Rethinking Ecology
PERSPECTIVES

Rethinking Ecology 4: 45–77 (2019)
doi: 10.3897/rethinkingecology.4.32570
http://rethinkingecology.pensoft.net

Opportunities to improve the future of South Australia's terrestrial biodiversity

Corey J. A. Bradshaw[1]

1 *Global Ecology, College of Science and Engineering, Flinders University, GPO Box 2100, South Australia 5001, Australia*

Corresponding author: *Corey J. A. Bradshaw* (corey.bradshaw@flinders.edu.au)

Academic editor: *S. Boyer* | Received 21 December 2018 | Accepted 27 March 2019 | Published 9 April 2019

Citation: Bradshaw CJA (2019) Opportunities to improve the future of South Australia's terrestrial biodiversity. Rethinking Ecology 4: 45–77. https://doi.org/10.3897/rethinkingecology.4.32570

Abstract

It is unequivocal that the poor condition of South Australia's terrestrial biodiversity is continuing to decline overall – much like elsewhere in Australia. This decline is mainly due to the legacy of vegetation clearing and habitat modification since European colonisation, the destructive influence of invasive species (especially predators like cats and foxes) on its native fauna and flora, and impotent or broken legislation to prevent further damage. The struggle to maintain our remaining biodiversity, and our intentions to restore once-healthy ecosystems, are rendered even more difficult by the added influence of rapid climate disruption. Despite the pessimistic outlook, South Australians have successfully employed several effective conservation mechanisms, including increasing the coverage of our network of protected areas, doing ecological restoration projects, reducing the densities of feral animals across landscapes, encouraging private landholders to protect their biodiversity assets, releasing environmental water flows to rivers and wetlands, and bringing more people in touch with nature. While these strategies are certainly stepping in the right direction, our policies and conservation targets have been hampered by arbitrary baselines, a lack of cohesion among projects and associated legislation, unrepresentative protected areas, and inappropriate spatial and time scales of intervention. While the challenges are many, there are several tractable and affordable actions that can be taken immediately to improve the prospect of the State's biodiversity into the near future. These include coordinating existing and promoting broader-scale ecological restoration projects, establishing strategic and evidence-based control of invasive species, planning more representative protected-area networks that are managed effectively for conservation outcomes, fixing broken environmental legislation, avoiding or severely limiting biodiversity-offset incentives, expanding conservation covenants on private land, coordinating a state-wide monitoring network and protocol that tells the South Australian community how effective we are with our policies and actions, expanding existing conservation investment and tapping into different funding schemes, and coordinating better communication and

Copyright *Corey J. A. Bradshaw.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

interaction among government and non-governmental environment agencies. Having a more transparent and defensible link between specific conservation actions and targeted outcomes will also likely improve confidence that conservation investments are well-spent. With just a little more effort, coordination, funding, and foresight, South Australia has the opportunity to become a pillar of biodiversity conservation.

Keywords
South Australia, biodiversity, conservation, restoration, environmental legislation, environmental policy, protected areas, invasive species, biodiversity offsets

Introduction

Despite Australia having a relatively small human population by global standards (25 million) and one of the lowest population densities in the world (3.25 km^{-2}) (Bradshaw and Brook 2016; World Bank 2018), Australia's terrestrial biodiversity is not doing well. Australia is home to an estimated 566,000 species, of which only about 150,000 have been described formally (Chapman 2009). Many of Australia's species are found nowhere else on Earth, including most of the more well-known marsupial mammals (about 87% of the described species are endemic), but also many different endemic birds (45%), reptiles (94%), fish, and plants (92%) (Chapman 2009). Unfortunately, Australia's track record in species loss is not necessarily in keeping with that expected from its low human population density and vast tracks of open spaces – indeed, Australia has the world's highest mammal extinction rate (Woinarski et al. 2015), and it has a legacy of deforestation from long-running policies encouraging landholders to clear native vegetation (Bradshaw 2012; Bradshaw and Ehrlich 2015; Evans 2016). Importantly, Australia also has an abundance of destructive invasive plant and animal species (Doherty et al. 2016) – from weeds, to voracious introduced predators like European foxes (*Vulpes vulpes*) and feral cats (*Felis catus*). These invasive plants and animals not only threaten native species that largely evolved in isolation from such pressures, they also cost Australia billions of dollars each year to control them and in lost economic opportunity (Bradshaw et al. 2016; Hoffmann and Broadhurst 2016). Australians also have a massive ecological footprint (footprintnetwork.com) – as a population we are using over four times what would be considered ecologically sustainable in the long term, due in part to our exorbitant per-capita greenhouse-gas emissions (25 t CO_2-e $person^{-1}$ yr^{-1}) (Bradshaw and Brook 2016) and water use (6300 l $person^{-1}$ day^{-1}; water-calculator.org). As such, a 2010 study calculated that Australia's overall environmental performance was the 9th worst of all nations in the world (Bradshaw et al. 2010), and Australia ranked 37th in the world on progress toward the United Nations' Sustainable Development Goals (Sachs et al. 2018).

Of course, Australia is not alone in its poor environmental performance, for the world as a whole is losing species approximately 1000 times faster than is expected from normal environmental variation (De Vos et al. 2014; Pimm et al. 2014). This elevated extinction rate is primarily caused by the economic activity of a 7.5 billion-strong and rising global human society (Bradshaw and Brook 2014), including the

direct exploitation of other species for food, deforestation mainly from agricultural expansion, the spread of non-native species into novel areas, pollution, and anthropogenic climate disruption (Griggs et al. 2013; Sodhi et al. 2009).

But can we hinder further onslaught of human endeavour on our natural life-support system? Through sound monitoring, smart environment and energy policies, and evidence-based interventions, I argue that we certainly have the means and financial capability of doing so; the question is more whether we have sufficient political leadership to achieve them at spatial and time scales meaningful to the preservation of our remaining biodiversity. In conjunction with the recently released (November 2018) *State of the Environment* report for the State of South Australia, I had the opportunity to review this State's terrestrial biodiversity prospects, and contemplate the ways in which its biodiversity can be best maintained and/or restored. In this *Perspective* paper, I outline several ways in which South Australia – a state of the Commonwealth of Australia covering nearly one million square kilometres – can, and hopefully will, improve the future prospects of its biodiversity and environmental performance. As a large geopolitical region of the world with many legacy and looming environmental problems, an in-depth discussion of its biodiversity-conservation challenges can provide guidance to many other areas of the world facing similar challenges. While I focus exclusively here on the State's terrestrial biodiversity (including freshwater habitats), the 2018 *State of the Environment* report also provides information on the status of South Australia's marine biodiversity.

State of South Australia's terrestrial biodiversity

One could assume that South Australia's direct human-population footprint might be less than that in the more populated eastern states of Australia (South Australia has only 7% of Australia's 25 million people); however, this assumption belies the long history of deforestation and habitat change done principally in the name of agricultural expansion since European colonisation. The infamy of clearing in Western Australia's wheatbelt from the 1940s to the 1980s (Bradshaw 2012; Saunders 1989) and Queensland's sporadic title as a world deforestation hotspot this century (Accad et al. 2006; Bradshaw 2012; Henry et al. 2005; Lepers et al. 2005; McAlpine et al. 2009) might overshadow the fact that most of South Australia's native vegetation clearing was done in the 19th and early 20th centuries (Bradshaw 2012; Szabo et al. 2011). Today, native forests cover only about 9% of the South Australia's land area, which is a substantial reduction in its pre-European cover. Indeed, by 1975 South Australia had cleared 75% of its native vegetation in its agricultural zone – approximately 20% of the total area of the State (Australian Greenhouse Office 2000; Bartel 2004; Evans 2016). For example, only < 10% of the original forest cover remains in the Mount Lofty Ranges (Fig. 1), and there is today < 4% forest cover remaining in the Adelaide Plains relative to its extent at European colonisation (Bradshaw 2012). As such, a Parliamentary Inquiry into the state of South Australia's biodiversity by the Environment, Resources, and Develop-

ment Committee concluded in 2017 that "… the condition of biodiversity in the State continues to decline" (Environment, Resources and Development Committee, 2017).

Given the overall loss of biodiversity nationally, and the well-established relative loss of species, habitats, and ecosystems in South Australia since European colonisation, the question of how to impede or slow future losses should not necessarily focus on the (probably impossible) task of bringing our environment back to a pre-European condition; instead, we should be asking whether our actions and political decisions are at least maintaining the *status quo*, or perhaps even improving the state of biodiversity in South Australia. Thus, the following sections summarise the current data describing the recent trends and conditions of the State's terrestrial biodiversity, discuss recent actions and policies that have slowed or have the potential to limit biodiversity loss, set realistic goals for improvement, recommend actions to reduce the risk of even more biodiversity losses, and identify gaps in our knowledge regarding what actions should be prioritised and best applied to maximise the resilience of South Australia's remaining terrestrial species.

Recent trends in South Australia's biodiversity

The cover in woody native vegetation (woodlands and shrublands) in South Australia over the last 25 years is approximately stable, with slight increases in the southern and central regions (Eyre Peninsula, Northern and Yorke, Adelaide and Mount Lofty Ranges, South Australian Murray-Darling Basin; Fig. 1); however, its overall condition is unknown (Government of South Australia 2018). Broadening our scope, overall native vegetation – including native grasslands – is in a State-wide decline in cover, with the regions doing the worst also those with the most people; like woody native vegetation, the condition of our remaining native vegetation is unknown (Government of South Australia 2018). At the species level, the abundance and distribution of native flora is also declining across the State, especially in the most-populated regions (Government of South Australia 2018). Like their animal counterparts (see below), 12% of native plant species are threatened with extinction across the State, of which the South East has the highest proportion (25%; Fig. 1).

Following the greater trend across Australia, South Australia's terrestrial fauna species have been declining in abundance and distribution overall, most notably in the most-populated regions of the State. Of these, 12% of South Australia's native animal species are considered threatened with extinction (Government of South Australia 2018), with the highest proportion of threatened species (23%) reported in the Adelaide and Mount Lofty Ranges (Fig. 1). As an example, many South Australian bird species are declining at alarming rates, and consequently have some of the highest risks of extinction relative to almost everywhere else in the country (Geyle et al. 2018).

Globally, the world has lost some two-thirds of its wetlands over the last century (Davidson 2014). Combined with the higher proportional risk of extinction for freshwater biodiversity relative to almost any other group of animals or plants (Balian et al. 2008; Dudgeon et al. 2006), and the high human demand for freshwater in Australia – the driest inhabited continent on Earth – freshwater species are perhaps the most threatened group in South Australia. Indeed, over 70% of the State's wetlands have

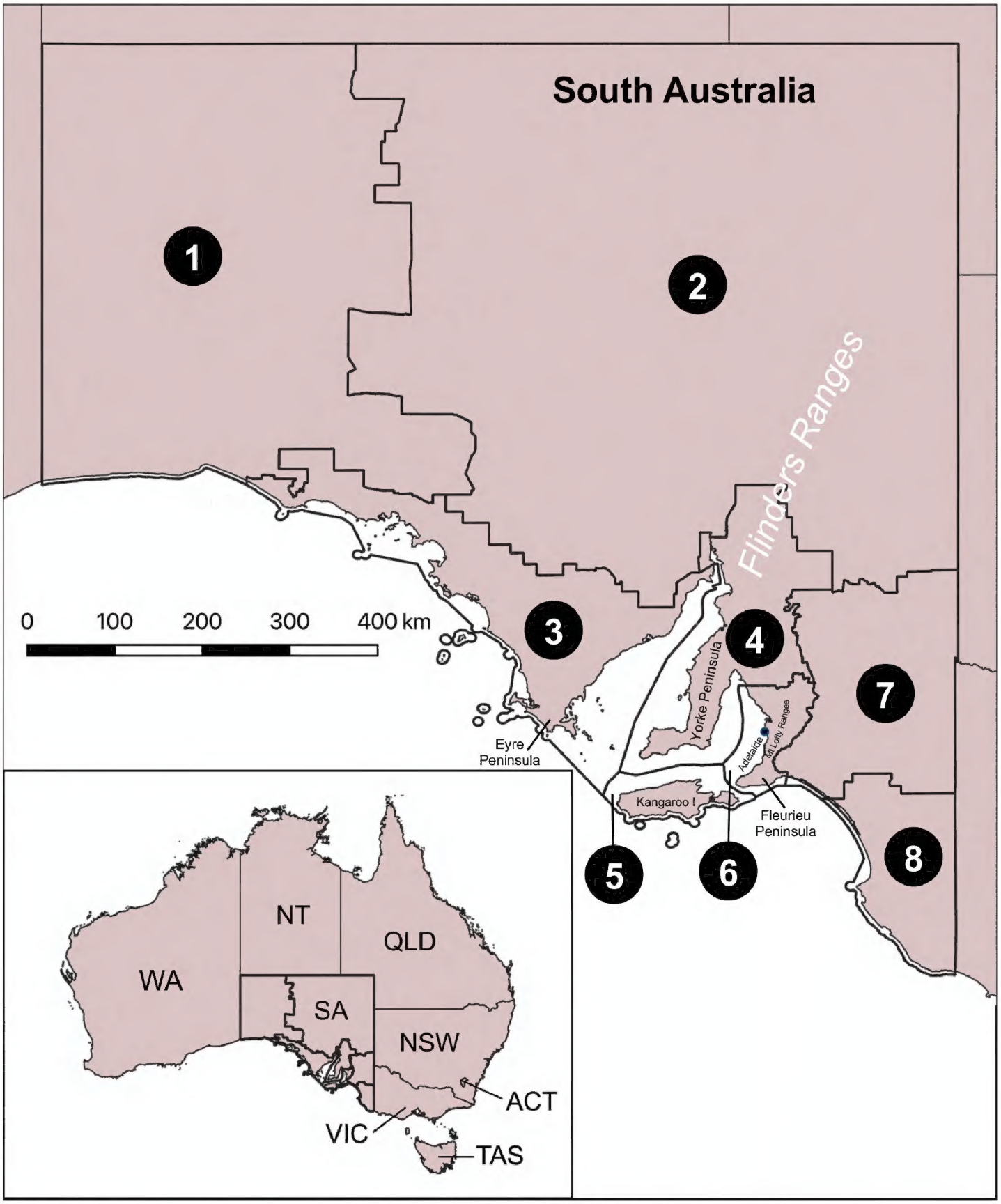

Figure 1. Map of South Australia, with major features mentioned in the paper indicated. Natural Resource Management regions are indicated by white numbers in black circles: 1: Alinytjara Wilurara, 2: SA Arid Lands, 3: Eyre Peninsula, 4: Northern and Yorke, 5: Kangaroo Island, 6: Adelaide and Mt Lofty Ranges, 7: SA Murray-Darling Basin, 8: South East. Inset: Map of Australia with states and territories indicated: WA = Western Australia, NT = Northern Territory, SA = South Australia, QLD = Queensland, NSW = New South Wales, VIC = Victoria, TAS = Tasmania, ACT = Australian Capital Territory.

been lost since European colonisation, and 99% of those remaining cannot be considered 'intact' (Government of South Australia 2003). Over the entire State, wetlands are considered 'stable'; however, most of its wetlands are found in only two regions (Adelaide and Mount Lofty Ranges and South East; Fig. 1), and the wetlands there

are declining in both area and condition (Government of South Australia 2018). That said, aquatic ecosystem condition in general is improving in many regions (except the wetland-rich South East), mainly as a result of more available environmental water since the Millennium drought (2001–2009) (Government of South Australia 2018). As for the State's rivers, streams and drains, they are classed overall as in 'fair' or 'poor' ecological condition in terms of nutrient concentrations, salt content, sediment load, vegetation type, weeds, and invertebrate communities (epa.sa.gov.au).

South Australia is now host to many weedy plants (e.g., African boxthorn *Lycium ferocissimum*, arum lily *Zantedeschia aethiopica*, flax-leaf broom *Genista linifolia*) (Government of South Australia 2018) and alien animal species (e.g., foxes, cats, feral goats *Capra hircus*, rats *Rattus* spp., dromedary camels *Camelus dromedarius*), with the situation worsening in terms of their increasing abundance and/or distribution mainly in the most populated regions of the State (Northern and Yorke, Adelaide and Mount Lofty Ranges, South East; Fig. 1) (Government of South Australia 2018).

Steps in the right direction

The preceding section's brief summary of the state of South Australia's terrestrial biodiversity might be viewed as pessimistic, but the collective realisation that there are problems to fix from a long history of environment reporting from various State-government bodies (e.g., Environment Protection Authority 2013; Mudge and Moss 2008; Nicolson et al. 2003), peer-reviewed sources (see *References*), and non-government agencies has stimulated a wide range of on-the-ground management interventions, as well as positive changes to policy. While we still have a long way to go to improve, we have already made some progress toward protecting the State's biodiversity and ecosystems.

Land clearing is by far the greatest threatening process to South Australia's terrestrial species (Bradshaw 2012; Evans 2016; Government of South Australia 2018), so it stands to reason that programs to revegetate previously cleared land with native plants have been emphasised throughout much of the State, and especially in its agricultural zones. Over several decades up until the present, many different revegetation programs have been initiated with the intent of bringing back some semblance of native forest and/or grassland function. Many of these have been small-scale ventures to assist in revegetating tracts of farmland, or others that have a broader-scale, regional focus (see Suppl. material 1 for more detail).

South Australia has also had some successes in reintroducing and restocking native wildlife in areas of the State where they are threatened with extinction, including species like yellow-footed rock wallabies (*Petrogale xanthopus*) to restored habitats in the Flinders Ranges (Zoos South Australia 2018), warru (black-footed rock wallabies *Petrogale lateralis*) in the northern Anangu-Pitjantjatjara-Yankunytjatjara ('APY') lands (Natural Resources Alinytjara Wilurara 2018), and western quolls (*Dasyurus geoffroii*) and brush-tailed possums (*Trichosurus vulpecula*) into the arid interior of South Australia (Natural Resources SA Arid Lands 2018) (Fig. 1; see more details in the Suppl. material 1).

Similarly, several programs to reduce the densities of invasive animal species have also been trialled successfully in the State. For example, invasive predators like feral cats and foxes – two of the most destructive invasive species in Australia in terms of their negative impacts on native wildlife (Doherty et al. 2017; Doherty et al. 2016; Woinarski et al. 2018; Woinarski et al. 2017) – have been successfully reduced or eradicated from small, fenced areas in several areas of the State (see more detail in Suppl. material 1). Likewise, feral goats, dromedary camels, various deer species, and European rabbits (*Oryctolagus cuniculus*) have been targeted for reductions in several regions (Suppl. material 1).

The recognition that natural water cycles in river courses and wetlands are fundamental to the maintenance of freshwater biodiversity has led to a recent re-emphasis on manipulating water via 'environmental flows'. While this recent shift in management of the State's water has yet to demonstrate concrete benefits to biodiversity, there are some signs that it could reduce some of the damage done previously (see Suppl. material 1). For wetlands in particular, the State has recently promoted the restoration of some small-scale sites, mostly within the Adelaide City region (Suppl. material 1), even though the State's overall wetland health is declining (Deane et al. 2017; Government of South Australia 2018).

South Australia has also increased the proportion of land set aside for the purposes of biodiversity conservation, albeit most of this is the semi-arid and arid regions of the State where there is relatively lower species richness and endemism compared to the wetter regions to the south (Government of South Australia 2018; Guerin et al. 2016). In the latter regions, under-representation of distinct ecosystems is high (Suppl. material 1). The State has also largely recognised the urgency with which its biodiversity-maintenance/restoration strategies must be implemented, although the scale and frequency of required changes to existing legislation mean that effectiveness has been low (Suppl. material 1). Finally, State authorities are becoming better at engaging people to value biodiversity and environmental integrity through various State- and privately run initiatives (Suppl. material 1). Land owners themselves can also enter into Heritage Agreements (Government of South Australia 2018), which essentially establish a conservation area on private land in perpetuity (i.e., even if the property is sold or ownership is otherwise transferred). These are positive in principle to encourage people to protect important conservation resources on private land, although there can be perverse outcomes if not managed correctly (see below).

Realistic goals for improvement

Remove 'no-extinction' targets

Before discussing specific opportunities that will likely improve the outcomes for biodiversity conservation in South Australia over the coming years, it pays to reflect on long-terms goals, and the possibility of realising them. The State currently has a policy of 'no species loss' (Government of South Australia 2018), which is laudable in princi-

ple, but an entirely unrealistic proposition because extinctions are impossible to avoid, at least over geological time scales (Raup 1986; Raup 1994). But it is incorrect to believe that because most of the environmental damage in South Australia has already been done, that we can now more easily avoid extinctions in the future. Unfortunately, extinction debt (Tilman et al. 1994) means that in many cases, past environmental degradation will still lead to future species losses, sometimes years, decades, and even centuries (Dullinger et al. 2013) past the causal environmental perturbations. Thus, even if comprehensive, State-wide, and broad-scale ecological conservation projects were to be planned and implemented in South Australia, there would still likely be decades of extinctions from past degradation. Combining this notion with the observation that few of the indicators used to track biodiversity change in South Australia are indicating any improvement, a no-loss policy becomes unachievable.

Fortunately, South Australia's environmental decision makers are beginning to rethink this approach through the multi-stakeholder partnership known as Nature of SA (natureofsa.org) – a sector-wide endeavour to support positive change in the State's holistic approach to nature conservation. While still in its early stages, this multi-institutional *conversation* (for it is not much more than that at this stage) is potentially bringing the greater community's conservation values more formally into line with government policies and future management endeavours. While this will most likely help align government policy with public values, by itself it will be insufficient to set realistic goals and implement actions for the conservation of South Australia's biodiversity.

South Australia therefore requires conservation goals that will enhance the resilience of the most species for the lowest costs. While I will describe specific opportunities for achieving this in the following sections, the essence of its policies should be testing improvement via effective monitoring, adaptive management, and the estimation of counterfactuals. First, because too few species, habitats, and ecosystems are adequately monitored and measured in South Australia, it is difficult, and in many cases impossible, to determine whether specific interventions actually improve the species they were intended to help (Lindenmayer et al. 2013; Reynolds et al. 2011). Second, there are typically insufficient efforts to estimate counterfactuals (i.e., what would happen otherwise) when proposing an intervention. Here, mathematical models that incorporate measured environmental variation, and projected trends in land-use and climate change, can be useful for testing business-as-usual scenarios against realistic intervention scenarios.

Generic priorities for conservation

In an overarching sense, the State's priorities for biodiversity conservation should therefore adhere to the following general approaches that are summarised from the more comprehensive set of conservation-planning standards provided by the *Open Standards for the Practice of Conservation* (cmp-openstandards.org): (1) determine which biodiversity values are most important to protect in the long-run to maintain ecosystem

function and evolutionary resilience; (2) measure whether these biodiversity values (e.g., using indices of abundance, distribution, condition of a population, species, or ecosystem) are changing over time; (3) if these measured values are declining, design an intervention that at least stops or slows the decline; and (4) test interventions (experimentally or by mathematical simulation) for their capacity to restore a population, species, or ecosystem towards an acceptable baseline (e.g., a minimum viable population size, a minimum proportion of formally occupied range, an accepted minimum number of populations, minimum number of species for ecosystems to continue functioning, etc.) (Traill et al. 2007; Traill et al. 2010; Zhang et al. 2012).

From the perspective of minimising the risk of a species going extinct, there is a vast scientific foundation for how many individuals (Traill et al. 2010), populations (Ceballos et al. 2017), genetic diversity (Frankham et al. 2014), and ecological functions (Hobbs et al. 2009; Walker 1992) are required to promote the long-term stability of biodiversity. Adding a little bit more of this scientific understanding into the planning mix will therefore help us to reach these minima. And if we manage to build populations up even beyond these minimum targets, the risk of extinction will likely decline even more.

It is also essential to appreciate that context matters – in other words, determining what species are at risk and what interventions are required will differ across landscapes. This can be true even for the same species or ecological communities in different areas. Thus, what works in one place will not necessarily work somewhere else if the pressures and landscape contexts are different, meaning that generic, one-action-fits-all approaches are unlikely to be successful everywhere.

Realistic baselines for recovery

Restoration goals are premised on establishing some sort of minimum *baseline* – that is, a state to which we aspire to return the system. Environmental purists in Australia often opine that this baseline should be the state of the environment at or around the time of European colonisation (Higgs et al. 2014; Kopf et al. 2015), but this naïve perspective ignores the notions that all ecosystems change through time, climate change has already or will make no-analogue futures for many species (García-López and Allué 2013; Urban et al. 2012), extensive landscape modification already largely precludes a return to pre-European states in most ecosystems, no one alive today knows what the pre-European state was (nor are there any data to estimate it), and there was substantial ecosystem modification by Indigenous Australians well before Europeans arrived (Bliege Bird et al. 2008; Bradshaw 2012; Flannery 1998; Johnson et al. 2016; Saltré et al. 2016). Returning to the priorities for conservation, we therefore need to establish conservation goals based on the ecological fundamentals of species *persistence* (Frankham et al. 2014), rather than adhering to arbitrary and unrealistic historical baselines (Higgs et al. 2014). This approach includes focussing on promoting ecological functions (e.g., pollination networks, soil nutrient flux, predator-prey dynamics)

(Devoto et al. 2012; Prober et al. 2005; Seddon et al. 2014) and evolutionary potential (Frankham et al. 2014; Hoffmann and Sgrò 2011) that strengthen an ecosystem's resilience to anthropogenic perturbations like climate change (Lunt et al. 2013), biological invasions (Bakker and Wilson 2004), infection from pathogens (Liu et al. 2017; Liu et al. 2016), and stochastic shocks (Beisner et al. 2003).

Opportunities

In this section I describe what I argue are some of the most tractable and affordable changes to existing management actions and policies that could result in the greatest conservation gains in South Australia over the next few decades.

Restoration

As I outlined earlier, the greatest threatening process in South Australia today for native flora and fauna is past and ongoing clearing of native vegetation (Government of South Australia 2018). Thus, (1) arresting further vegetation clearing, and (2) restoring previously cleared land to functional native-vegetation communities are easily the highest priorities across the entire State. I discuss the first aspect (preventing clearing) in more detail below, so I will focus here instead on the restoration component.

Despite some valiant attempts across the State to revegetate previously cleared areas (Suppl. material 1), the haphazard approach to reforestation in South Australia means that we are unlikely to be maximising ecological function and providing the best habitats for native flora and fauna. Several improvements in this regard can be made:

(1) Establish a State Register of past, ongoing, and planned revegetation projects, including data on the proponents, area revegetated, species planted, number of individuals planted for each species, monitoring in place (e.g., plant survival, other species using the restored habitat, etc.), and costs (actual or projected). Such a State Register would allow for a more regional coordination of future revegetation projects to suggest potentially more ecologically useful approaches. This could include identifying the most locally suitable species to plant, maximising the area of existing native habitat or restored fragments by planting adjacent to these, joining isolated islands of habitat to increase connectivity, or even to create more efficient projects by combining otherwise independent proponents (e.g., adjacent landholders).
(2) Establish a State Revegetation Council that uses data from the Register to prioritise projects, enhance collaboration, and suggest improvements in design and placement according to the principles mentioned above. The Council could also help coordinate monitoring of progress and ecological outcomes at the landscape scale. Part of the Council's mandate could be to design landscape-scale adaptive-management approaches (Doak et al. 2008) that formalise partnerships between

scientists, resource managers, and the public (Fujitani et al. 2017; Walters and Holling 1990); here, species recovery, efficient planting experiments, and ecological-community responses could be experimentally manipulated in different combinations to achieve desired conservation outcomes efficiently (e.g., Serrouya et al. 2019). The Council could also apply this approach to design restoration plans that explicitly take climate-change projections into account, thus foreshadowing range shifts and adapting to these explicitly by considering connectivity across shifting environmental gradients (Seddon et al. 2014).

A State Register for Wetland Restoration and a relevant Council could be established in a similar manner, emphasising the conservation and restoration of smaller wetlands with more unique, endemic plant species (Deane et al. 2017). Likewise, both Councils could ideally assist in coordinating non-profit and private organisations in terms of their revegetation priorities, as well as coordinate with conservation covenants (see below) for private landholders.

Perhaps the best example of a large-scale project to enhance habitat connectivity in Australia is the ambitious (yet, so far incomplete) *Gondwana Link* (gondwanalink.org), which is attempting to link fragments of bushland together into a contiguous habitat feature. Operating in southern Western Australia, the program is aiming to achieve complete forest connectivity over about 1000 km, from the dry woodlands of the interior, to the tall, wet forests of the far south-west corner of that State. By restoring the native vegetation in the gaps between forest fragments, the overall aim is to build a contiguous forest over this entire range. Given that good connectivity is an important feature of habitats that improves the conservation prospects of the many species living within them by allowing these species to move freely among populations, and by increasing the overall size of the available habitat (Crooks and Sanjayan 2006) (but see Doerr et al. 2011; Hodgson et al. 2009), *Gondwana Link* represents, if fully realised, one of the greatest potential conservation achievements in Australia's history. South Australia used to have an analogous program known as *NatureLinks* (Government of South Australia 2014), from which successful projects like *Bounceback* emerged (Natural Resources SA Arid Lands 2018). However, Commonwealth and State funding for the program dried up several years ago, and it is unfortunately no longer planned. A return to a *NatureLinks*-like program would achieve many conservation gains for the State of South Australia.

(3) Most revegetation projects in South Australia are not specifically linked to particular conservation outcomes. Thus, establishing what specific goals the revegetation intends to have (e.g., expanding the available habitat for specific species) will help design projects of sufficient magnitude and composition for the intended outcomes. As far as is practical, approaches should therefore follow the National Standards for the Practice of Ecological Restoration in Australia (Standards Reference Group of the Society for Ecological Restoration Australasia 2018), which are based on six main principles: (*i*) practice is based on an appropriate local indigenous reference ecosystem; (*ii*) restoration inputs are dictated by resilience and degradation; (*iii*) recovery of ecosystem attributes is facilitated by identifying clear targets, goals, and

objectives; (*iv*) the goal is full recovery, insofar as possible, even if outcomes take long or involve high inputs; (*v*) restoration science and practice are synergistic; and (*vi*) social aspects are critical to successful ecological restoration (Standards Reference Group of the Society for Ecological Restoration Australasia 2018).

(4) All restoration projects should ideally incorporate carbon accounting to estimate the carbon-sequestration component (realised and potential) of restoration projects for carbon assessments legislated under Australia's commitment to the Kyoto Protocol. Australia committed to reduce its greenhouse-gas emissions by ratifying the Kyoto Protocol in 2007 (United Nations 1998), and then signed up to the second commitment period (2013–2020) under the Paris Agreement (United Nations 2016). As part of the National Greenhouse and Energy Reporting Act 2007, Australia is obliged to account for all emissions and sequestration.

(5) There is currently a lack of empirical evidence regarding the most effective ways to maximise the potential for biodiversity recovery and maintenance in revegetation projects (i.e., which species to plant, how many different species to plant, what spacing to plant, etc.), while there are some ongoing experiments to determine these ideal approaches for certain habitats in South Australia (there are also examples of carefully designed restoration experiments elsewhere in Australia; e.g., Charles et al. 2018; Ladouceur and Mayfield 2017), there is as yet insufficient information across all vegetation communities in South Australia to provide ideal guidelines.

Invasive species control

If vegetation clearing is among the greatest threats to South Australia's remaining biodiversity, then invasive species (predators, in particular) are certainly comparable. While local attempts to reduce the density of species like foxes and cats in particular are admirable (Suppl. material 1), insufficient effort and longevity of the projects in many cases do little to reduce actual predator densities. Ideal culling regimes to maximise the reduction in densities that have real, positive implications for native prey typically require some modelling beforehand to guide the effort needed to achieve success (e.g., McMahon et al. 2010). While such models are in development for the places like Kangaroo Island (Natural Resources Kangaroo Island 2018), most density-reduction programs do not employ these powerful planning tools. Thus, culling regimes not only have to demonstrate empirical evidence that efforts will succeed in reducing densities, they must also demonstrate that target predator reductions translate into real declines in predation pressure on native prey. Culling programs therefore need to be sufficiently funded, they need to occur over long-enough time frames to avoid only temporarily reducing predators, they need to be integrated across the landscape to dovetail with other conservation goals, and they also need to monitor their progress. Without these essential ingredients, most projects end up doing nothing more than wasting money and time without helping any native species.

In terms of overall priorities for animal species to cull, this will be site-specific, but in general we should be aiming to reduce (*a*) cats, then (*b*) foxes, (*c*) rabbits, (*d*) goats, (*e*) camels, and (*f*) deer based on the following justifications: (*i*) cats and foxes have contributed the most to mammal extinctions in Australia, and represent mounting pressures for many threatened vertebrates (Doherty et al. 2015; Doherty et al. 2017; Woinarski et al. 2015; Woinarski et al. 2018; Woinarski et al. 2017), (*ii*) rabbits are a major agricultural pest in Australia (Barnett et al. 2018), and have extensive negative impacts for native plants and animals (Burrell et al. 2017; Pedler et al. 2016), and (*iii*) the specific economic and biodiversity impacts of the invasive obligate herbivores (goats, camels, and deer) are poorly quantified in South Australia, although they probably represent less of a threat to terrestrial biodiversity on the whole compared to cats and foxes. For weeds, the eradication priorities are likely to be highly site-specific, and should follow the Weeds of National Significance priorities (Australian Government 2012) based on known and projected ecological and economic impacts.

Protected areas

While South Australia might boast a large proportional coverage of its land area under some form of protection (as of March 2018: 359 protected areas covering > 21 million hectares, or 21.5% of State's total area; these values exclude Indigenous Protected Areas; environment.sa.gov.au), there is high under-representation of certain areas and habitats with the most unique native species (i.e., especially in the wetter, southern parts of the State; Fig. 2 and Suppl. material 1). Thus, our goal should be to avoid arbitrary overall targets of coverage, and instead plan on increasing the coverage of our most endangered, and under-represented habitats (e.g., wetlands, moist temperate forests, native grasslands, etc.). Finding crown or Indigenous land outside private holdings to protect can be politically challenging and/or expensive, but we should at least model ideal spatial patterns for maximising representativeness using established approaches (Lechner et al. 2015; Moilanen et al. 2009; Watts et al. 2017). Of course, this includes planning for the climates of the future (Keppel et al. 2015), as well as for projected fire and urbanisation trends (Bardsley et al. 2015).

Planning for effective and representative networks of protected areas should follow the principles of Comprehensive, Adequate and Representative Reserve Systems (Government of South Australia 2017) – this approach essentially (*i*) allows for the special needs of rare or threatened species, communities or ecosystems, (*ii*) caters for special groups of organisms that have complex habitat requirements, are mobile or migratory, and (*iii*) includes important areas that have high species diversity, or act as natural refugia. Thus, merely adding new reserves to the network opportunistically will not lead to adequate representation of the ecological communities most in need of protection (e.g., see Fig. 2). Perhaps more importantly, each protected area requires sufficient management to be able to function as intended, and this requires adequate

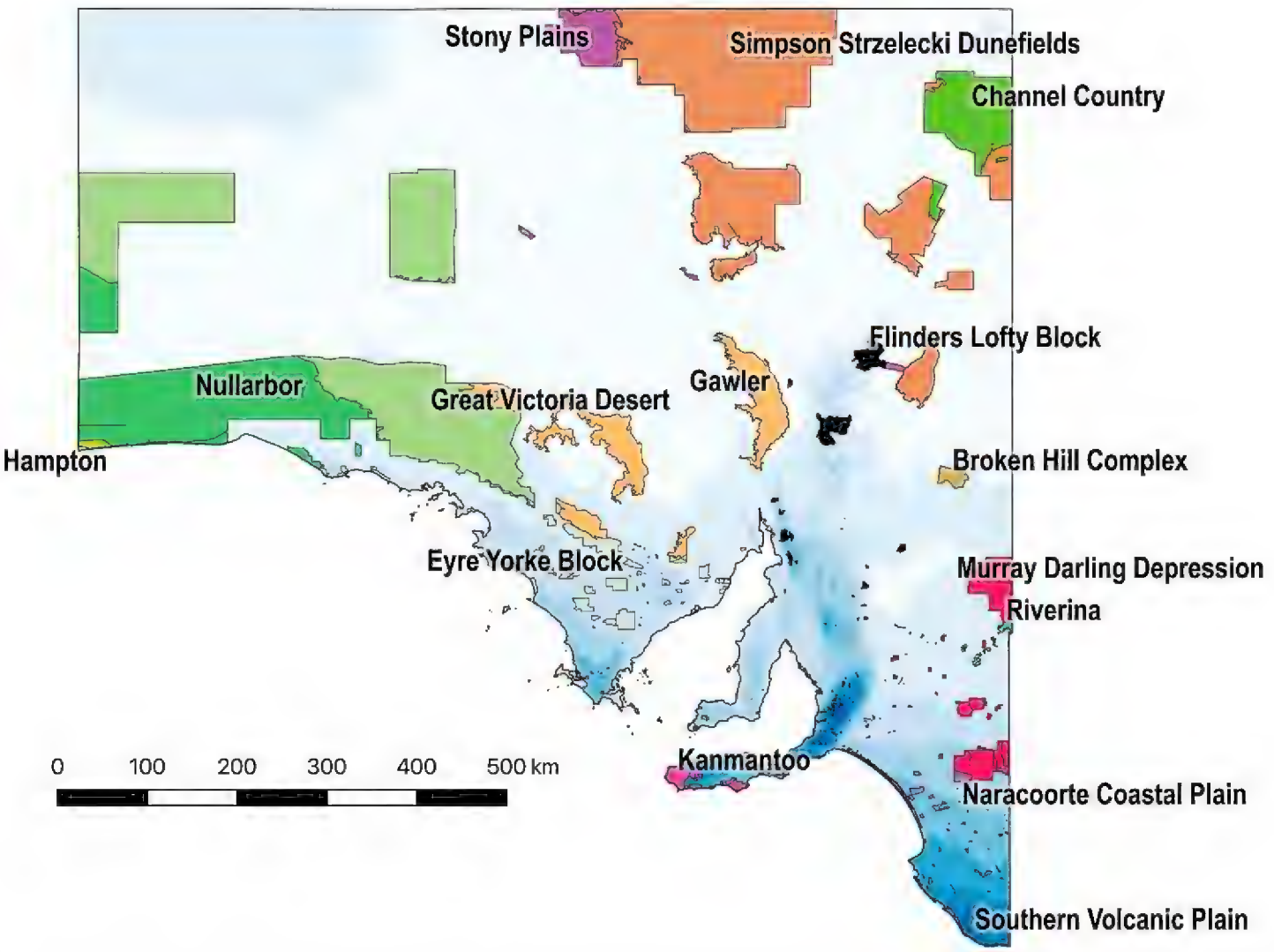

Figure 2. Overlaying the State of South Australia's Protected Areas boundary data ('Conservation Reserve Boundaries'; data.sa.gov.au) with the Interim Biogeographic Regionalisation for Australia (IBRA Version 7; environment.gov.au) layer indicates that 73.2% of the total protected area (excluding Indigenous Protected Areas) in South Australia lies in the arid biogeographic regions of Great Victoria Desert (21.1%), Channel Country (15.2%), Simpson Strzelecki Dunefields (14.0%), Nullarbor (9.8%), Stony Plains (6.6%), Gawler (6.0%), and Hampton (0.5%). The total biogeographic-region area covered by the remaining Conservation Reserves amounts to 26.2% (Murray Darling Depression 10.0%, Riverina 4.8%, Flinders Lofty Block 3.3%, Eyre Yorke Block 3.1%, Broken Hill Complex 2.8%, Naracoorte Coastal Plain 1.2%, Southern Volcanic Plain 1.2%, and Kanmantoo 0.4%). Background blue shading indicates relative average annual rainfall (data from bom.gov.au). Comparing the distribution of the Conservation Reserves with maps of South Australia's plant species richness and endemicity from Guerin et al. (2016) demonstrates clearly that most of the protected-area network within the state therefore covers regions of lowest plant richness and endemicity (Suppl. material 1: Fig. S1).

funding and planning. Merely gazetting a reserve and then doing nothing more will nearly always ensure continued biodiversity loss within (Geldmann et al. 2015).

But if we only relied on traditional protected areas like reserves, conservation areas, and national parks to protect biodiversity, we would likely fail to avoid extinctions, mainly because most land area is under private ownership. This point was recently echoed strongly by the South Australia Parliamentary Inquiry into Biodiversity (Environment, Resources and Development Committee 2017). Thus, coordination with landholders to improve agricultural practices that harm wildlife, establish conservation covenants or Heritage Agreements, and exclude livestock and other species from

conservation assets, must occur in tandem. Further, increasing biodiversity conservation in urban environments (Goddard et al. 2010), with specific, biodiversity-focussed planning of green spaces in cities using landscape-ecology frameworks, will assist in promoting biodiversity persistence in urban and peri-urban regions of the State.

Fix inadequate legislation

Surprisingly, there is no specific article of legislation that covers all aspects of biodiversity conservation and environmental management in South Australia today. Separate acts that cover some elements include the Native Vegetation Act that restricts clearing, the National Parks and Wildlife Act 1972 that deals with protected areas and species endangerment, the Wilderness Protection Act 1992 that addresses wilderness protection and land restoration, the Natural Resource Management Act 2004 that promotes sustainable and integrated management of the State's natural resources, and the Environment Protection Authority (epa.sa.gov.au) that operates under various acts (including the Aquaculture Act 2001, Environmental Protection Act 1993, Radiation Protection and Control Act 1982, and the Wingfield Waste Depot Closure Act 1999) to limit environmental damage (all South Australian Acts can be viewed at legislation.sa.gov.au). Even these acts with some relevance to biodiversity do not consider invertebrates (like insects) as animals – because most animals are in fact invertebrates (Wilson 1987), this means that most of South Australia's species are ineligible for official threat listing or protection, even if they have a high risk of extinction.

Indeed, the 2017 Parliamentary Inquiry into Biodiversity concluded that existing environmental legislation in South Australia "… lacks cohesion and consistency, particularly regarding enforcement and compliance provisions" (Environment, Resources and Development Committee 2017). An entirely new, biodiversity-focussed act would therefore add legislative teeth to biodiversity conservation in this State – in fact, the Parliamentary Inquiry into Biodiversity recommended the creation of a Biodiversity Expert Panel to reform the legislative framework of environmental protection (Environment, Resources and Development Committee 2017), and the new (elected 17 March 2018) Government of South Australia has the perfect opportunity to do so under their proposed changes to natural resource management legislation (Liberal Party of South Australia 2018). Following these calls for reform and the new direction of Nature of SA (natureofsa.org), there is a real opportunity here for statutory reform that includes integrated biodiversity legislation analogous to the New South Wales Biodiversity Conservation Act 2016 (legislation.nsw.gov.au).

While broad-scale clearing of vegetation in South Australia was limited in 1991 with the implementation of the Native Vegetation Act, each year in South Australia there are between 1000 and 2000 hectares legally cleared, as administered by the Native Vegetation Council (Government of South Australia 2017), and > 200 hectares cleared illegally (Bradshaw 2012; Environment Protection Authority 2013). Better enforcement (and a suggested increase in financial penalties for non-

compliance) of the Native Vegetation Act notwithstanding, there are some problems with the current operation and rules governing the restrictions on clearing native vegetation. First, The Council needs better connection to the planning process for projects proposing to clear native vegetation. In many circumstances, the planning is done before consulting the Council, so that it becomes a case of approve/not approve, instead of being able to influence the planning from the outset. It should be a legal requirement of development proponents to seek advice from the Council *before* project planning commences.

However, the biggest weakness of the Native Vegetation Act is the ability for separate legislation to be created at the discretion of the sitting government to circumvent this and other relevant Acts. Under the Development Act 1993 (Section 46), if a development is successfully assessed as 'major' (an arbitrary and subjective category), it can under certain circumstances be permitted to bypass and completely ignore all restrictions of the Native Vegetation Act via the passing of new, dominant legislation. This occurred recently with the approval of the Bend Motorsport Park (thebend.com.au) when it lobbied for (Strathearn 2014), and was granted, special compensation to clear unique native vegetation without the approval of the Native Vegetation Council (Parnell 2016). This sort of special compensation undermines the entire Act, and renders the Native Vegetation Council's oversight toothless. This requires immediate rectification because the practice of allowing commercial interests to circumvent the Act essentially permits the largest and most biodiversity-destructive developments to go ahead unhindered (Environment, Resources and Development Committee, 2017).

Analogously, most vegetation clearances allowed by The Council within the last few years have been for the development of renewable-energy projects like wind and solar-photovoltaic farms (Native Vegetation Council, *personal communication*), yet the Act does not specifically address renewable-energy developments. While the addition of low-carbon energy facilities is certainly a positive for the State's low-carbon energy generation, if development comes at the cost of native vegetation in all circumstances, the net outcomes for biodiversity could, in fact, be negative. The Act therefore needs to be updated to include renewable-energy developments.

As is often the case, the Council's administrative burden is high, such that applications for small-scale clearances (e.g., < 5 ha) might work better under some regimented framework of self-assessment. This could be supported by regional Natural Resource Management staff. Finally, Heritage Agreements unfortunately have some perverse outcomes for retaining native vegetation. Existing Heritage Agreements preclude any form of development, such that new property owners who wish to reside within their 'bush blocks' are precluded from constructing eco-friendly homes under existing legislation. To encourage environmentally conscious 'tree-changers', this impediment could be relaxed on a case-by-case basis. Also, Heritage Agreements appear overly restrictive with respect to applying conservation interventions like controlled burns and the removal of weedy plant species.

Biodiversity offsets

While biodiversity offsets are becoming more popular with state and Commonwealth agencies as a means to raise money for conservation and restoration, while simultaneously promoting economic development (Maron et al. 2015), there are many perverse consequences for biodiversity if they are not set up carefully (Bekessy et al. 2010; Maron et al. 2015; Nature Conservation Council of NSW 2016). Biodiversity 'offsets' are intended to work in a similar way to carbon offsets, in that the destruction of a part of an ecosystem (e.g., a native forest or grassland, or a wetland) can be *offset* by paying to fund the restoration of another, similar ecosystem elsewhere. As such, approval to clear native vegetation usually comes with financial and other conditions (e.g., see South Australia's offsetting rules as they pertain to 'Significant Environmental Benefits', meaning that an offset needs to provide an environmental gain beyond the damage done to the native vegetation targeted for clearing – this is the concept of 'additionality') (van Oosterzee et al. 2012).

But there are many problems with biodiversity offsetting (Gordon 2011), including the inconvenient fact that creating an equivalent ecosystem somewhere takes substantially longer than it does to destroy one somewhere else (e.g., Martin et al. 2013). While carbon emitted in one place is essentially the same as that sequestered elsewhere, a forest can take hundreds of years to develop the same biodiversity values and ecological functions it had prior to destruction. As such, it is generally acknowledged that existing state-level biodiversity offsetting schemes have failed (e.g., Nature Conservation Council of NSW 2016), and might be doing more long-term harm than good; (Maron and Gordon 2013); in fact, many have concluded that biodiversity offsetting has little hope of ever working as originally intended (Apostolopoulou and Adams 2017; Maron et al. 2015; Walker et al. 2009). Thus, while biodiversity offsetting might look good on paper, and it can provide funding for restoration projects, it has to be done following a strict set of rules (Maron et al. 2012) for it to have any hope of maintaining biodiversity in the long run. Thus, biodiversity offsetting should only be used sparingly in South Australia (if at all), and under the strictest set of rules and supervision.

Conservation covenants

In addition to voluntary Heritage Agreements, landholders in South Australia can choose to participate in establishing a type of easement on their land that acts specifically as a *conservation covenant*. Such covenants on a title restrict the landholder's 'rights' (e.g., to graze, clear, develop, etc.). While there is nearly no ongoing official government support (financial or otherwise) for such endeavours, the program has had some success in encouraging voluntary conservation on private land (Greiner 2016) via reverse auctions funded sometimes, perversely, from biodiversity-offset schemes (although other funding sources exist, such as State and Commonwealth government grant schemes).

Reverse auctions (*cf.* 'typical' land conservation auctions and payment policies; Connor et al. 2008) operate generally as a voluntary process where a private landholder (1) is asked if she/he desires to manage a conservation asset (e.g., a forest fragment) differently than the *status quo*, or restore a habitat/species, (2) estimates the magnitude of change that this different form of management/intervention will have for the conservation value, (3) invokes a specific management plan with assistance from a conservation professional, (4) estimates the amount that this change will cost, and (5) is provided that money through government or other sources of funding if the cost is competitive when ranked against other landholder offers. A South Australian example – *Bushbids* – has had some success using this approach (O'Connor et al. 2008).

The problems of insufficient funding notwithstanding, reverse auctions of conservation covenants might have a more positive role in promoting the communication of conservation values among stakeholders than immediate conservation gains *per se*. Still, there are several impediments to its wide application in South Australia. For example, the good work that not-for-profit organisations like Greening Australia (greeningaustralia.org.au) do in terms of planting services can in fact outcompete third-party companies from bidding to restore or manage a conservation asset on private land. Thus, the delivery of quality services to landholders unwilling to spend their time and money to protect or enhance biodiversity on their land are largely unavailable. Further, much of the pricing associated with biodiversity management on private land is only loosely estimated, but there are few empirical data quantifying what landholders will actually gain from the process. Also, entry-level covenant schemes with few commitments could assist in convincing many dubious landholders that the process is beneficial, such that they are ultimately more willing to participate eventually in broader-scale and more sophisticated schemes (i.e., a 'try before you buy' approach). Finally, many untargeted initiatives are divorced from landscape-scale planning of restoration, so linking with a State Revegetation Council could assist in this regard.

Monitoring

A persistent weakness with our assessments of the condition of South Australia's environment is a lack of rigorous, long-term monitoring that clearly measures how our State's biodiversity values are changing over time. This is clear with the lack of incontrovertible condition assessments for our native vegetation and aquatic ecosystems in particular. In conjunction with State authorities planning and monitoring the progress of revegetation projects (for example), a state-wide system of monitoring points should be established for the most important and underrepresented biodiversity values. Indicator species and ecosystems should be identified by a dedicated committee based on representativeness, degree of threat, and distribution, and protocols for basic monitoring established (e.g., surveys of abundance, water quality, counts of species present, condition, etc.). A coordinated, State-wide monitoring system could revolutionise not only how we understand the trending fate of our ecosystems, it would assuredly assist in planning better restoration and conservation plans over the coming decades (Lindenmayer et al. 2012).

Funding

State Government funding for the environment is currently hovering between 1.0–1.5% of annual State Budget expenditures, or between $100 million and $150 million per year (Fig. 3). The main feature of government spending on the environment is the steady decline overall since the early 2000s (Fig. 3). Despite appearing substantial to some not familiar with the high costs of environmental management and restoration (McCarthy et al. 2012; Menz et al. 2013), the amount spent in South Australia is vastly inferior to what would be required to restore, preserve and enhance its threatened biodiversity values. However, a major government funding boost is unlikely in the near term (if ever), even though arresting further budget declines would be advisable. Other funding streams are possible, including Commonwealth-level initiatives (e.g., Caring for Our Country; Australian Government 2018), private acquisitions and investments (e.g., Arid Recovery; aridrecovery.org.au), and offset programs. The latter category includes both biodiversity offsets (most likely not a large source of funding itself, nor a particularly good idea) and carbon offsets, with the latter representing perhaps the greatest source of new funding should restoration programs be directly tied to mandatory carbon-accounting schemes (Bradshaw et al. 2013).

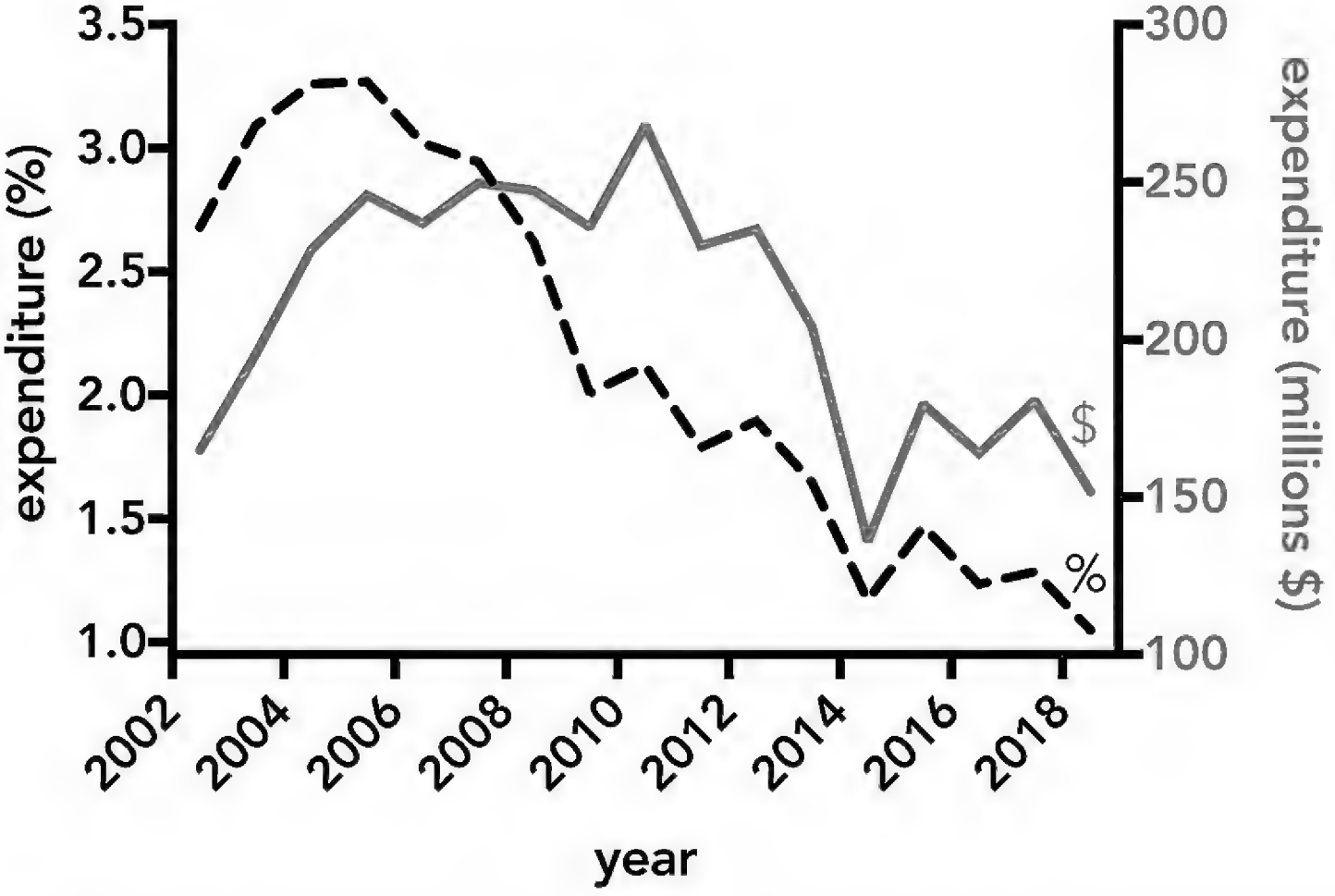

Figure 3. South Australia budget expenditures on environment (total $ and % of total) from 2002–2003 to 2017–2018. Given changes to departmental responsibilities, these should be considered only indicative; includes environment, water, heritage, and Environment Protection Authority portfolios (source: South Australia Department of Treasury and Finance – treasury.sa.gov.au).

Energy

The production of energy – electricity, transport fuels, and industrial heat for manufacturing – is intimately tied to biodiversity conservation in this State. From mining uranium, to fracking natural gas, to vegetation clearing for renewable-energy installations, to bird and bat deaths from striking wind turbines, to climate-change mitigation via emissions reductions, a society that ignores the role of energy production in environmental protection risks losing even more biodiversity (Brook and Bradshaw 2015). Further, societies that promote 100% renewable-energy instead of 0% carbon pathways are likely doomed to rely on a substantial component of their energy production from fossil fuels (especially in most of Australia that lacks large hydro or geothermal resources), and the burning of environmentally destructive biofuels (Heard et al. 2015). As such, different government agencies tasked with managing the environment and energy are required to collaborate to avoid perverse outcomes for biodiversity.

Multi-agency cooperation

As discussed above, the creation of Nature of SA (natureofsa.org) is a step in the right direction towards cohesion of the often fragmented environmental and political agendas of different government and non-government organisations. However, Nature of SA currently lacks legislative teeth, and has only really begun the conversation between groups. An independent, non-government body should be established to coordinate the various environmental-interest groups, government agencies, councils and boards, such that consensus statements are agreed and co-signed. This could help develop strong societal value statements and subsequent funding and policy outcomes that favour biodiversity conservation in South Australia.

Longer-term levers

There are many other steps South Australia could take to improve its biodiversity outcomes that I will only mention briefly, for they require vastly greater research and development than the suggested improvements discussed thus far. Different government and private agencies could promote all, or at least some of the following in the course of their normal operations to provide real biodiversity benefits. For example, emphasis on the development of more biodiversity-friendly agriculture that spares native habitats (Phalan et al. 2011) is an obvious course of action – this includes land-sparing approaches (Dotta et al. 2015; Hulme et al. 2013; Kamp et al. 2015; Kremen 2015; Williams et al. 2017), restoration of adjacent native vegetation to promote the persistence of wild pollinators (Carvalheiro Luísa et al. 2011), rotational grazing (Ravetto Enri et al. 2017; Waters et al. 2016), reducing stocking density (Dorrough et al. 2006; Fynn and O'Connor 2001; Jansen and Healey 2003; Jansen and Robertson 2001), payments for ecosystem services (Smith and Sullivan 2014), agricultural intensification instead of expansion (Tilman et al. 2011; Tscharntke

et al. 2005) in areas already highly compromised (to reduce the incentives to clear even more land for agriculture), among many other approaches (Jackson 1997).

Many ecologists today promote the use of dingoes (*Canis dingo*) to alleviate predation on native fauna from introduced predators like cats and foxes. South Australia's official position on dingoes is that they are an agricultural pest; in fact, dingoes and dog-dingo hybrids are classified as 'wild dogs' inside (south of) the 5400-km Dog Fence (PIRSA 2018) under the Natural Resources Management Act 2004 (despite dingoes being recognised as a distinct species from other dogs; Smith et al. 2019), but outside the Fence they are considered 'native' (but unprotected) under the National Parks and Wildlife Act 1972 (and therefore have some acknowledged ecological value there). Non-dingo dogs are considered 'declared pests' under the Natural Resources Management Act 2004 and the Dog and Cat Management Act 1995. While controversial and currently at odds with the State's official stance, there is mounting evidence that allowing dingoes into the southern rangelands would benefit biodiversity (Glen et al. 2007; Nimmo et al. 2015; Ritchie et al. 2012; Ritchie and Johnson 2009; Smith et al. 2019), and in some cases possibly increase profit margins for cattle farmers (Prowse et al. 2015). A more engaged discussion between Biosecurity South Australia, the pastoral sector, and environmental agencies regarding the pros and cons of dingoes for biodiversity enhancement, as well as the tractability of different management options for pastoralists, should therefore be encouraged.

The success of Indigenous Protected Areas in conserving land for multiple cultural and biodiversity values has been a positive step for biodiversity conservation across Australia; however, these are mainly restricted to more remote areas with relatively lower biodiversity than the more populated regions to the south. Broader engagement with Aboriginal peoples in all aspects of biodiversity conservation on private and public lands will undoubtedly increase the likelihood of positive biodiversity and social outcomes. Increasing cultural awareness among non-Indigenous Australians is also a potential drawcard for bringing people into more frequent and lasting contact with natural values and Indigenous cultures.

Finally, there are several important knowledge gaps with respect to maximising the retention of South Australia's existing biodiversity. For example, revegetation and ecological restoration in general stand to have the greatest positive impacts on biodiversity maintenance and recovery, provided they can be done at spatial scales large enough to reduce the extinction risk of many species simultaneously. Thus, we require much better information regarding which combinations of species are needed for planting to maximise the biodiversity values of the habitats they will eventually create. Likewise, the role of carbon offsetting to fund both the planning and implementation of major restoration projects cannot be understated. However, detailed, habitat-specific soil, wetland, grassland, and forest carbon-storage capacities and potential are still poorly measured across Australia (Bradshaw et al. 2013). Perhaps most urgently, the imminent effects of climate change on South Australia's ecological communities is less well-understand than our predictions of how the climate itself will change over the coming decades (Intergovernmental Panel on Climate Change 2014; Intergovernmental Panel on Climate Change 2018; Montazerolghaem et al. 2016). Community-level models of how important habitats will change over time are necessary to be able to plan the most effective restoration and conservation objectives.

Conclusions

While better and broader scientific information will most certainly help in our quest to maintain and enhance South Australia's biodiversity, the most challenging issues that remain are more social, economic, and psychological in nature than they are scientific. In other words, our challenges are related more to managing *people* and their choices and behaviours, rather than biodiversity *per se*. The human element in biodiversity conservation therefore cannot be understated, so the important task of managing ourselves is essential for long-term success in our conservation approaches. From encouraging people to value nature, to amending legislation that limits destructive economic development, to providing a viable business framework for maintaining, financing, and restoring biodiversity on public and private lands – these all play the most important roles in today's biodiversity-conservation challenges. If we forget *the people* in our quest to save *other species*, we are doomed to fail; but if we include everyone in the challenge, we will prevail.

Acknowledgements

I thank E. Jenke (democracyCo.com.au), P. O'Connor (oconnornrm.com.au), C. Daniels (clelandwildlifepark.sa.gov.au), D. Rogers (South Australia Department for Environment and Water), and T. Hills (epa.sa.gov.au) for advice, insight, and direction. A version of this paper appeared as a commissioned report to the South Australia Environment Protection Authority in November 2018 (epa.sa.gov.au/soe-2018/issues/biodiversity).

Author contribution

Designed and wrote the manuscript: CJAB (100 %). Prepared the figures: CJAB (100 %).

Authors	Contribution	ACI
CJAB	1.00	*NA*

References

Accad A, Neldner VJ, Wilson BA, Niehus RE (2006) Remnant Vegetation in Queensland. Analysis of Remnant Vegetation 1997–1999–2000–2001–2003, Including Regional Ecosystem Information. Queensland Herbarium, Environmental Protection Agency, Brisbane.

Apostolopoulou E, Adams WM (2017) Biodiversity offsetting and conservation: reframing nature to save it. Oryx 51: 23–31. https://doi.org/10.1017/S0030605315000782

Australian Government (2012) Weeds of National Significance. Canberra. http://www.environment.gov.au/biodiversity/invasive/weeds/weeds/lists/wons.html

Australian Government (2018) Previous programmes. National Landcare Program, Canberra. http://www.nrm.gov.au/news-and-resources/resources/previous-programmes

Australian Greenhouse Office (2000) Land Clearing: A Social History. National Carbon Accounting System Technical Report No. 4. Commonwealth of Australia, Canberra, Australia.

Bakker JD, Wilson SD (2004) Using ecological restoration to constrain biological invasion. Journal of Applied Ecology 41: 1058–1064. https://doi.org/10.1111/j.0021-8901.2004.00962.x

Balian EV, Segers H, Martens K, Lévéque C (2008) The freshwater animal diversity assessment: an overview of the results. In: Freshwater Animal Diversity Assessment. Springer, Dordrech, 627–637.

Bardsley DK, Weber D, Robinson GM, Moskwa E, Bardsley AM (2015) Wildfire risk, biodiversity and peri-urban planning in the Mt Lofty Ranges, South Australia. Applied Geography 63: 155–165. https://doi.org/10.1016/j.apgeog.2015.06.012

Barnett LK, Prowse TAA, Peacock DE, Mutze GJ, Sinclair RG, Kovaliski J, Cooke BD, Bradshaw CJA (2018) Previous exposure to myxoma virus reduces survival of European rabbits during outbreaks of rabbit haemorrhagic disease. Journal of Applied Ecology. https://doi.org/10.1111/1365-2664.13187

Bartel RL (2004) Satellite imagery and land clearance legislation: a picture of regulatory efficacy? Australasian Journal of Natural Resources Law and Policy 9: 1–31.

Beisner BE, Haydon DT, Cuddington K (2003) Alternative stable states in ecology. Frontiers in Ecology and the Environment 1: 376–382. https://doi.org/10.1890/1540-9295(2003)001[0376:ASSIE]2.0.CO;2

Bekessy SA, Wintle BA, Lindenmayer DB, McCarthy MA, Colyvan M, Burgman MA, Possingham HP (2010) The biodiversity bank cannot be a lending bank. Conservation Letters 3: 151–158. https://doi.org/10.1111/j.1755-263X.2010.00110.x

Bliege Bird R, Bird DW, Codding BF, Parker CH, Jones JH (2008) The "fire stick farming" hypothesis: Australian Aboriginal foraging strategies, biodiversity, and anthropogenic fire mosaics. Proceedings of the National Academy of Science of the USA 105: 14796–14801. https://doi.org/10.1073/pnas.0804757105

Bradshaw CJA (2012) Little left to lose: deforestation and forest degradation in Australia since European colonization. Journal of Plant Ecology 5: 109–120. https://doi.org/10.1093/jpe/rtr038

Bradshaw CJ, Bowman DM, Bond NR, Murphy BP, Moore AD, Fordham DA, Thackway R, Lawes MJ, McCallum H, Gregory SD, Dalal RC (2013) Brave new green world – consequences of a carbon economy for the conservation of Australian biodiversity. Biological Conservation 161: 71–90. https://doi.org/10.1016/j.biocon.2013.02.012

Bradshaw CJA, Brook BW (2014) Human population reduction is not a quick fix for environmental problems. Proceedings of the National Academy of Science of the USA 111: 16610–16615. https://doi.org/10.1073/pnas.1410465111

Bradshaw CJA, Brook BW (2016) Implications of Australia's population policy for future greenhouse-gas emissions targets. Asia & the Pacific Policy Studies 3: 249–265. https://doi.org/10.1002/app5.135

Bradshaw CJA, Ehrlich PR (2015) Killing the Koala and Poisoning the Prairie: Australia, America, and the Environment, University of Chicago Press, Chicago.

Bradshaw CJA, Giam X, Sodhi NS (2010) Evaluating the relative environmental impact of countries. PLoS One 5: e10440. https://doi.org/10.1371/journal.pone.0010440

Bradshaw CJA, Leroy B, Bellard C, Roiz D, Albert C, Fournier A, Barbet-Massin M, Salles J-M, Simard F, Courchamp F (2016) Massive yet grossly underestimated global costs of invasive insects. Nature Communications 7: 12986.

Brook BW, Bradshaw CJA (2015) Key role for nuclear energy in global biodiversity conservation. Conservation Biology. https://doi.org/10.1111/cobi.12433

Burrell AL, Evans JP, Liu Y (2017) Detecting dryland degradation using time series segmentation and residual trend analysis (TSS-RESTREND). Remote Sensing of Environment 197: 43–57. https://doi.org/10.1016/j.rse.2017.05.018

Carvalheiro LG, Veldtman R, Shenkute AG, Tesfay GB, Pirk CWW, Donaldson JS, Nicolson SW (2011) Natural and within-farmland biodiversity enhances crop productivity. Ecology Letters 14: 251–259. https://doi.org/10.1111/j.1461-0248.2010.01579.x

Ceballos G, Ehrlich PR, Dirzo R (2017) Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. Proceedings of the National. Academy of Science of the USA 114: 6089–6096. https://doi.org/10.1073/pnas.1704949114

Chapman AD (2009) Numbers of Living Species in Australia and the World (2nd edn). Report for the Australian Biological Resources Study, Canberra. https://www.environment.gov.au/system/files/pages/2ee3f4a1-f130-465b-9c7a-79373680a067/files/nlsaw-2nd-complete.pdf

Charles LS, Dwyer JM, Smith TJ, Connors S, Marschner P, Mayfield MM (2018) Species wood density and the location of planted seedlings drive early-stage seedling survival during tropical forest restoration. Journal of Applied Ecology 55: 1009–1018. https://doi.org/10.1111/1365-2664.13031

Connor JD, Ward JR, Bryan B (2008) Exploring the cost effectiveness of land conservation auctions and payment policies. The Australian Journal of Agricultural and Resource Economics 52: 303–319. https://doi.org/10.1111/j.1467-8489.2007.00417.x

Crooks KR, Sanjayan M (2006) Connectivity Conservation. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511754821

Davidson NC (2014) How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine & Freshwater Research 65: 934–941. https://doi.org/10.1071/MF14173

De Vos JM, Joppa LN, Gittleman JL, Stephens PR, Pimm SL (2014) Estimating the normal background rate of species extinction. Conservation Biology 29: 452–462. https://doi.org/10.1111/cobi.12380

Deane DC, Fordham DA, He F, Bradshaw CJA (2017) Future extinction risk of wetland plants is higher from individual patch loss than total area reduction. Biological Conservation 209: 27–33. https://doi.org/10.1016/j.biocon.2017.02.005

Devoto M, Bailey S, Craze P, Memmott J (2012) Understanding and planning ecological restoration of plant–pollinator networks. Ecology Letters 15: 319–328. https://doi.org/10.1111/j.1461-0248.2012.01740.x

Doak DF, Estes JA, Halpern BS, Jacob U, Lindberg DR, Lovvorn J, Monson DH, Tinker MT, Williams TM, Wootton JT, Carroll I, Emmerson M, Micheli F, Novak M (2008) Under-

standing and predicting ecological dynamics: are major surprises inevitable? Ecology 89: 952–961. https://doi.org/10.1890/07-0965.1

Doerr VAJ, Barrett T, Doerr ED (2011) Connectivity, dispersal behaviour and conservation under climate change: a response to Hodgson et al. Journal of Applied Ecology 48: 143–147. https://doi.org/10.1111/j.1365-2664.2010.01899.x

Doherty TS, Davis RA, van Etten EJB, Algar D, Collier N, Dickman CR, Edwards G, Masters P, Palmer R, Robinson S (2015) A continental-scale analysis of feral cat diet in Australia. Journal of Biogeography 42: 964–975. https://doi.org/10.1111/jbi.12469

Doherty TS, Dickman CR, Johnson CN, Legge SM, Ritchie EG, Woinarski JCZ (2017) Impacts and management of feral cats *Felis catus* in Australia. Mammal Review 47: 83–97. https://doi.org/10.1111/mam.12080

Doherty TS, Glen AS, Nimmo DG, Ritchie EG, Dickman CR (2016) Invasive predators and global biodiversity loss. Proceedings of the National Academy of Science of the USA 113: 11261–11265. https://doi.org/10.1073/pnas.1602480113

Dorrough J, Moxham C, Turner V, Sutter G (2006) Soil phosphorus and tree cover modify the effects of livestock grazing on plant species richness in Australian grassy woodland. Biological Conservation 130: 394–405. https://doi.org/10.1016/j.biocon.2005.12.032

Dotta G, Phalan B, Silva TW, Green R, Balmford A (2015) Assessing strategies to reconcile agriculture and bird conservation in the temperate grasslands of South America. Conservation Biology 30: 618–627. https://doi.org/10.1111/cobi.12635

Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Leveque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ, Sullivan CA (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81: 163–182. https://doi.org/10.1017/S1464793105006950

Dullinger S, Essl F, Rabitsch W, Erb K-H, Gingrich S, Haberl H, Hülber K, Jarošík V, Krausmann F, Kühn I, Pergl J, Pyšek P, Hulme PE (2013) Europe's other debt crisis caused by the long legacy of future extinctions. Proceedings of the National Academy of Science of the USA 110: 7342–7347. https://doi.org/10.1073/pnas.1216303110

Environment, Resources and Development Committee (2017) Biodiversity. Seventy-eighth Report. Parliament of South Australia, Adelaide, South Australia.

Environment Protection Authority (2013) State of the Environment South Australia. Adelaide, South Australia.

Evans MC (2016) Deforestation in Australia: drivers, trends and policy responses. Pacific Conservation Biology 22: 130–150. https://doi.org/10.1071/PC15052

Flannery TF (1998) The Future Eaters: An Ecological History of the Australian Lands and People. Reed New Holland, Australia.

Frankham R, Bradshaw CJA, Brook BW (2014) Genetics in conservation management: revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. Biological Conservation 170: 56–63. https://doi.org/10.1016/j.biocon.2013.12.036

Fujitani M, McFall A, Randler C, Arlinghaus R (2017) Participatory adaptive management leads to environmental learning outcomes extending beyond the sphere of science. Science Advances 3: e1602516. https://doi.org/10.1126/sciadv.1602516

Fynn RWS, O'Connor TG (2001) Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. Journal of Applied Ecology 37: 491–507. https://doi.org/10.1046/j.1365-2664.2000.00513.x

García-López JM, Allué C (2013) Modelling future no-analogue climate distributions: a worldwide phytoclimatic niche-based survey. Global and Planetary Change 101: 1–11. https://doi.org/10.1016/j.gloplacha.2012.12.001

Geldmann J, Coad L, Barnes M, Craigie ID, Hockings M, Knights K, Leverington F, Cuadros IC, Zamora C, Woodley S, Burgess ND (2015) Changes in protected area management effectiveness over time: a global analysis. Biological Conservation 191: 692–699. https://doi.org/10.1016/j.biocon.2015.08.029

Geyle HM, Woinarski JCZ, Baker GB, Dickman CR, Dutson G, Fisher DO, Ford H, Holdsworth M, Jones ME, Kutt A, Legge S, Leiper I, Loyn R, Murphy BP, Menkhorst P, Reside AE, Ritchie EG, Roberts FE, Tingley R, Garnett ST (2018) Quantifying extinction risk and forecasting the number of impending Australian bird and mammal extinctions. Pacific Conservation Biology 24: 157–167. https://doi.org/10.1071/PC18006

Glen AS, Dickman CR, Soulé ME, Mackey BG (2007) Evaluating the role of the dingo as a trophic regulator in Australian ecosystems. Austral Ecology 32: 492–501. https://doi.org/10.1111/j.1442-9993.2007.01721.x

Goddard MA, Dougill AJ, Benton TG (2010) Scaling up from gardens: biodiversity conservation in urban environments. Trends in Ecology & Evolution 25: 90–98. https://doi.org/10.1016/j.tree.2009.07.016

Gordon A (2011) Biodiversity offsets: solving the habitat-saving equation. The Conversation. https://theconversation.com/biodiversity-offsets-solving-the-habitat-saving-equation-4035

Government of South Australia (2003) Wetlands Strategy for South Australia. Department for Environment and Heritage, Adelaide, South Australia. https://www.environment.sa.gov.au/files/sharedassets/public/wetlands/wetlands_strategy.pdf

Government of South Australia (2014) NatureLinks. Department for Environment and Heritage, Adelaide, South Australia. https://www.environment.sa.gov.au/files/6a64dbd5-b437-4610-a67d-a0e300c9adcb/About_Naturelinks.pdf

Government of South Australia (2017) CARRS program. Department for Environment and Water, Adelaide, South Australia. www.environment.sa.gov.au/managing-natural-resources/Park_management/New_parks_park_additions/carrs-program

Government of South Australia (2017) Native Vegetation Council. Department for Environment and Water, Adelaide, South Australia. www.environment.sa.gov.au/about-us/boards-and-committees/native-vegetation-council

Government of South Australia (2018) Heritage Agreements. Adelaide, South Australia: Department for Environment and Water. www.environment.sa.gov.au/topics/native-vegetation/protecting-enhancing/heritage-agreements

Government of South Australia (2018) No species loss. Department for Environment and Water, Adelaide, South Australia. www.environment.sa.gov.au/topics/Ecosystem_conservation/No_species_loss

Government of South Australia (2018) Tracking Changes in South Australia's Environment. Department for Environment and Water, Adelaide, South Australia. https://data.environment.sa.gov.au/Content/Publications/Summary%20of%20approach%20brochure.pdf

Government of South Australia (2018) Weed Control Handbook for Declared Plants in South Australia. Department of Environment and Water, Adelaide, South Australia. https://pir.sa.gov.au/__data/assets/pdf_file/0020/232382/WEB_8867_PIRSA_Weed_Control_Handbook_2018.pdf

Greiner R (2016) Factors influencing farmers' participation in contractual biodiversity conservation: a choice experiment with northern Australian pastoralists. The Australian Journal of Agricultural and Resource Economics 60: 1–21. https://doi.org/10.1111/1467-8489.12098

Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I (2013) Sustainable development goals for people and planet. Nature 495: 305. https://doi.org/10.1038/495305a

Guerin GR, Biffin E, Baruch Z, Lowe AJ (2016) Identifying centres of plant biodiversity in South Australia. PLoS One 11: e0144779. https://doi.org/10.1371/journal.pone.0144779

Heard B, Bradshaw CJA, Brook BW (2015) Beyond wind: furthering developing of clean energy in South Australia. Transactions of The Royal Society of South Australia 139: 57–82. https://doi.org/10.1080/03721426.2015.1035217

Henry BK, Mitchell C, Cowie A, Woldring O, Carter J (2005) A regional interpretation of rules and good practice for greenhouse accounting: northern Australian savanna systems. Australian Journal of Botany 53: 589–605. https://doi.org/10.1071/BT04200

Higgs E, Falk DA, Guerrini A, Hall M, Harris J, Hobbs RJ, Jackson ST, Rhemtulla JM, Throop W (2014) The changing role of history in restoration ecology. Frontiers in Ecology and the Environment 12: 499–506. https://doi.org/10.1890/110267

Hobbs RJ, Higgs E, Harris JA (2009) Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24: 599–605. https://doi.org/10.1016/j.tree.2009.05.012

Hodgson JA, Thomas CD, Wintle BA, Moilanen A (2009) Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology 46: 964–969. https://doi.org/10.1111/j.1365-2664.2009.01695.x

Hoffmann AA, Sgrò CM (2011) Climate change and evolutionary adaptation. Nature 470: 479–485. https://doi.org/10.1038/nature09670

Hoffmann BD, Broadhurst LM (2016) The economic cost of managing invasive species in Australia. NeoBiota 31: 1–18. https://doi.org/10.3897/neobiota.31.6960

Hulme MF, Vickery JA, Green RE, Phalan B, Chamberlain DE, Pomeroy DE, Nalwanga D, Mushabe D, Katebaka R, Bolwig S, Atkinson PW (2013) Conserving the birds of Uganda's banana-coffee arc: land sparing and land sharing compared. PLoS One 8: e54597. https://doi.org/10.1371/journal.pone.0054597

Intergovernmental Panel on Climate Change (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability. IPCC WGII AR5 Technical Summary, Geneva.

Intergovernmental Panel on Climate Change (2018) Global Warming of 1.5 °C. Summary for Policymakers, Geneva.

Jackson L (1997) Ecology in Agriculture. Academic Press, San Diego.

Jansen A, Healey M (2003) Frog communities and wetland condition: relationships with grazing by domestic livestock along an Australian floodplain river. Biological Conservation 109: 207–219. https://doi.org/10.1016/S0006-3207(02)00148-9

Jansen A, Robertson AI (2001) Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. Journal of Applied Ecology 38: 63–75. https://doi.org/10.1046/j.1365-2664.2001.00557.x

Johnson CN, Alroy J, Beeton NJ, Bird MI, Brook BW, Cooper A, Gillespie R, Herrando-Pérez S, Jacobs Z, Miller GH, Prideaux GJ, Roberts RG, Rodríguez-Rey M, Saltré F, Turney CSM, Bradshaw CJA (2016) What caused extinction of the Pleistocene megafauna of Sahul? Proceedings of the Royal Society B 283: 52399. https://doi.org/10.1098/rspb.2015.2399

Kamp J, Urazaliev R, Balmford A, Donald Paul F, Green Rhys E, Lamb Anthony J, Phalan B (2015) Agricultural development and the conservation of avian biodiversity on the Eurasian steppes: a comparison of land-sparing and land-sharing approaches. Journal of Applied Ecology 52: 1578–1587. https://doi.org/10.1111/1365-2664.12527

Keppel G, Mokany K, Wardell-Johnson GW, Phillips BL, Welbergen JA, Reside AE (2015) The capacity of refugia for conservation planning under climate change. Frontiers in Ecology and the Environment 13: 106–112. https://doi.org/10.1890/140055

Kopf RK, Finlayson M, Humphries P (2015) Anthropocene means changing our ideas of success. The Conversation. https://theconversation.com/restoring-and-conserving-nature-in-the-anthropocene-means-changing-our-idea-of-success-42691

Kremen C (2015) Reframing the land-sparing/land-sharing debate for biodiversity conservation. Annals of the New York Academy of Sciences 1355: 52–76. https://doi.org/10.1111/nyas.12845

Ladouceur E, Mayfield MM (2017) The early response of subtropical tussock grasslands to restoration treatments. Restoration Ecology 25: 689–695. https://doi.org/10.1111/rec.12491

Lechner AM, Brown G, Raymond CM (2015) Modeling the impact of future development and public conservation orientation on landscape connectivity for conservation planning. Landscape Ecology 30: 699–713. https://doi.org/10.1007/s10980-015-0153-0

Lepers E, Lambin EF, Janetos AC, Defries R, Achard F, Ramankutty N, Scholes RJ (2005) A synthesis of information on rapid land-cover change for the period 1981–2000. BioScience 55: 115–124. https://doi.org/10.1641/0006-3568(2005)055[0115:ASOIOR]2.0.CO;2

Liberal Party of South Australia (2018) Natural Resources Management. Adelaide, South Australia. http://strongplan.com.au/policy/natural-resources-management/

Lindenmayer DB, Piggott MP, Wintle BA (2013) Counting the books while the library burns: why conservation monitoring programs need a plan for action. Frontiers in Ecology and the Environment 11: 549–555. https://doi.org/10.1890/120220

Lindenmayer DB, Zammit C, Attwood SJ, Burns E, Shepherd CL, Kay G, Wood J (2012) A novel and cost-effective monitoring approach for outcomes in an Australian biodiversity conservation incentive program. PLoS One 7: e50872. https://doi.org/10.1371/journal.pone.0050872

Liu X, Lyu S, Sun D, Bradshaw CJA, Zhou S (2017) Species decline under nitrogen fertilization increases community-level competence of fungal diseases. Proceedings of the Royal Society B 284: 20162621. https://doi.org/10.1098/rspb.2016.2621

Liu X, Lyu S, Zhou S, Bradshaw CJA (2016) Warming and fertilization alter the dilution effect of host diversity on disease severity. Ecology 97: 1680–1689. https://doi.org/10.1890/15-1784.1

Lunt ID, Byrne M, Hellmann JJ, Mitchell NJ, Garnett ST, Hayward MW, Martin TG, McDonald-Maddden E, Williams SE, Zander KK (2013) Using assisted colonisation to conserve biodiversity and restore ecosystem function under climate change. Biological Conservation 157: 172–177. https://doi.org/10.1016/j.biocon.2012.08.034

Maron M, Gordon A (2013) Biodiversity offsets could be locking in species decline. The Conversation. https://theconversation.com/biodiversity-offsets-could-be-locking-in-species-decline-14177

Maron M, Gordon A, Mackey BG, Possingham HP, Watson JEM (2015) Stop misuse of biodiversity offsets. Nature 523: 401–403. https://doi.org/10.1038/523401a

Maron M, Hobbs RJ, Moilanen A, Matthews JW, Christie K, Gardner TA, Keith DA, Lindenmayer DB, McAlpine CA (2012) Faustian bargains? Restoration realities in the context of biodiversity offset policies. Biological Conservation 155: 141–148. https://doi.org/10.1016/j.biocon.2012.06.003

Martin PA, Newton AC, Bullock JM (2013) Carbon pools recover more quickly than plant biodiversity in tropical secondary forests. Proceedings of the Royal Society B 280: 20132236. https://doi.org/10.1098/rspb.2013.2236

McAlpine CA, Etter A, Fearnside PM, Seabrook L, Laurance WF (2009) Increasing world consumption of beef as a driver of regional and global change: a call for policy action based on evidence from Queensland (Australia), Colombia and Brazil. Global Environmental Change 19: 21–33. https://doi.org/10.1016/j.gloenvcha.2008.10.008

McCarthy DP, Donald PF, Scharlemann JPW, Buchanan GM, Balmford A, Green JMH, Bennun LA, Burgess ND, Fishpool LDC, Garnett ST, Leonard DL, Maloney RF, Morling P, Schaefer HM, Symes A, Wiedenfeld DA, Butchart SHM (2012) Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. Science 338: 946–949. https://doi.org/10.1126/science.1229803

McMahon CR, Brook BW, Collier N, Bradshaw CJA (2010) Spatially explicit spreadsheet modelling for optimizing the efficiency of reducing invasive animal density. Methods in Ecology and Evolution 1: 53–68. https://doi.org/10.1111/j.2041-210X.2009.00002.x

Menz MHM, Dixon KW, Hobbs RJ (2013) Hurdles and opportunities for landscape-scale restoration. Science 339: 526. https://doi.org/10.1126/science.1228334

Moilanen A, Wilson KA, Possingham H (2009) Spatial Conservation Prioritization: Quantitative Methods and Computational Tools. Oxford University Press, Oxford.

Montazerolghaem M, Vervoort W, Minasny B, McBratney A (2016) Spatiotemporal monthly rainfall forecasts for south-eastern and eastern Australia using climatic indices. Theoretical and Applied Climatology 124: 1045–1063. https://doi.org/10.1007/s00704-015-1457-3

Mudge S, Moss M (2008) The State of Our Environment. State of the Environment Report for South Australia 2008. Environment Protection Authority, Adelaide, South Australia. https://www.epa.sa.gov.au/soe_2008/home.html

Natural Resources Alinytjara Wilurara (2018) Warru recovery program. Government of South Australia, Adelaide, South Australia. http://www.naturalresources.sa.gov.au/alinytjara-wilurara/projects/warru-recovery-program

Natural Resources Kangaroo Island (2018) Kangaroo Island feral cat eradication program. Government of South Australia, Adelaide, South Australia. http://www.naturalresources.sa.gov.au/kangarooisland/plants-and-animals/pest-animals/Kangaroo-Island-Feral-Cat-Eradication-Program

Natural Resources SA Arid Lands (2018) Bounceback – building resilience across the ranges. Government of South Australia, Adelaide, South Australia. http://www.naturalresources.sa.gov.au/aridlands/plants-and-animals/native-plants-and-animals/bounceback

Natural Resources SA Arid Lands (2018) Western quoll (idnya) and brushtail possum (virlda) reintroduction to the Flinders Ranges. Government of South Australia, Adelaide, South Australia. http://www.naturalresources.sa.gov.au/aridlands/plants-and-animals/native-plants-and-animals/bounceback/western-quoll-idnya

Nature Conservation Council of New South Wales (2016) Paradise Lost – The weakening and widening of NSW biodiversity offsetting schemes, 2005–2016. Sydney. https://www.nature.org.au/media/265228/bio-offsetting-report_v14.pdf

Nicolson C, Payne J, Wallace J (2003) State of the Environment Report for South Australia 2003. Environment Protection Authority, Adelaide, South Australia. https://www.epa.sa.gov.au/data_and_publications/state_of_the_environment_reporting/soe_2003

Nimmo DG, Watson SJ, Forsyth DM, Bradshaw CJA (2015) Dingoes can help conserve wildlife and our methods can tell. Journal of Applied Ecology 52: 281–285. https://doi.org/10.1111/1365-2664.12369

O'Connor P, Morgan A, Bond A (2008) BushBids: Biodiversity Stewardship in the Eastern Mount Lofty Ranges, South Australia. South Australian Murray-Darling Basin Natural Resources Management Board, Adelaide, South Australia. http://www.oconnornrm.com.au/images/reports/Eastern_Mt_Lofty_Ranges_BushBids.pdf

Parnell M (2016) Greens Motion: Protection of Native Vegetation. Legislative Council of South Australia, Adelaide, South Australia. http://www.markparnell.org.au/speech.php?speech=1442

Pedler RD, Brandle R, Read JL, Southgate R, Bird P, Moseby KE (2016) Rabbit biocontrol and landscape-scale recovery of threatened desert mammals. Conservation Biology 30: 774–782. https://doi.org/10.1111/cobi.12684

Phalan B, Onial M, Balmford A, Green RE (2011) Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333: 1289. https://doi.org/10.1126/science.1208742

Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO (2014) The biodiversity of species and their rates of extinction, distribution, and protection. Science 344: 1246752. https://doi.org/10.1126/science.1246752

PIRSA (2018) Dog Fence. Primary Industries and Regions South Australia, Adelaide, South Australia. http://www.pir.sa.gov.au/biosecurity/weeds_and_pest_animals/animal_pests_in_south_australia/established_pest_animals/wild_dogs/dog_fence

Prober SM, Thiele KR, Lunt ID, Koen TB (2005) Restoring ecological function in temperate grassy woodlands: manipulating soil nutrients, exotic annuals and native perennial grasses through carbon supplements and spring burns. Journal of Applied Ecology 42: 1073–1085. https://doi.org/10.1111/j.1365-2664.2005.01095.x

Prowse TAA, Johnson CN, Cassey P, Bradshaw CJA, Brook BW (2015) Ecological and economic benefits to cattle rangelands of restoring an apex predator. Journal of Applied Ecology 52: 455–466. https://doi.org/10.1111/1365-2664.12378

Raup DM (1986) Biological extinction in Earth history. Science 231: 1528–1533. https://doi.org/10.1126/science.11542058

Raup DM (1994) The role of extinction in evolution. Proceedings of the National Academy of Science of the USA 91: 6758–6763. https://doi.org/10.1073/pnas.91.15.6758

Ravetto Enri S, Probo M, Farruggia A, Lanore L, Blanchetete A, Dumont B (2017) A biodiversity-friendly rotational grazing system enhancing flower-visiting insect assemblages while

maintaining animal and grassland productivity. Agriculture, Ecosystems & Environment 241: 1–10. https://doi.org/10.1016/j.agee.2017.02.030

Reynolds JH, Thompson WL, Russell B (2011) Planning for success: identifying effective and efficient survey designs for monitoring. Biological Conservation 144: 1278–1284. https://doi.org/10.1016/j.biocon.2010.12.002

Ritchie EG, Elmhagen B, Glen AS, Letnic M, Ludwig G, McDonald RA (2012) Ecosystem restoration with teeth: what role for predators? Trends in Ecology & Evolution 27: 265–271. https://doi.org/10.1016/j.tree.2012.01.001

Ritchie EG, Johnson CN (2009) Predator interactions, mesopredator release and biodiversity conservation. Ecology Letters 12: 982–998. https://doi.org/10.1111/j.1461-0248.2009.01347.x

Sachs J, Schmidt-Traub G, Kroll C, Lafortune G, Fuller G (2018) SDG Index and Dashboards Report 2018. Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN), New York. https://www.sdgindex.org/reports/2018/

Saltré F, Rodríguez-Rey M, Brook BW, Johnson CN, Turney CSM, Alroy J, Cooper A, Beeton N, Bird MI, Fordham DA, Gillespie R, Herrando-Pérez S, Jacobs Z, Miller GH, Nogués-Bravo D, Prideaux GJ, Roberts RG, Bradshaw CJA (2016) Climate change not to blame for late Quaternary megafauna extinctions in Australia. Nature Communications 7: 10511. https://doi.org/10.1038/ncomms10511

Saunders DA (1989) Changes in the avifauna of a region, district and remnant as a result of fragmentation of native vegetation: the wheatbelt of Western Australia. A case study. Biological Conservation 50: 99–135. https://doi.org/10.1016/0006-3207(89)90007-4

Seddon PJ, Griffiths CJ, Soorae PS, Armstrong DP (2014) Reversing defaunation: restoring species in a changing world. Science 345: 406–412. https://doi.org/10.1126/science.1251818

Serrouya R, Seip DR, Hervieux D, McLellan BN, McNay RS, Steenweg R, Heard DC, Hebblewhite M, Gillingham M, Boutin S (2019) Saving endangered species using adaptive management. Proceedings of the National Academy of Science of the USA: 201816923. https://doi.org/10.1073/pnas.1816923116

Smith BP, Cairns KM, Adams JW, et al. (2019) Taxonomic status of the Australian dingo: the case for *Canis dingo* Meyer, 1793. Zootaxa 4564: 173–197. https://doi.org/10.11646/zootaxa.4564.1.6

Smith HF, Sullivan CA (2014) Ecosystem services within agricultural landscapes–farmers' perceptions. Ecological Economics 98: 72–80. https://doi.org/10.1016/j.ecolecon.2013.12.008

Sodhi NS, Brook BW, Bradshaw CJA (2009) Causes and consequences of species extinctions. In: Levin SA (Ed.) The Princeton Guide to Ecology. Princeton University Press, Princeton, 514–520.

Standards Reference Group of the Society for Ecological Restoration Australasia (2018) National standards for the practice of ecological restoration in Australia. Edition 2.1. Society for Ecological Restoration Australasia, Canberra, Australia. https://www.seraustralasia.com

Strathearn P (2014) Tailem Bend moter sport plans revealed. The Murray Valley Standard. https://www.murrayvalleystandard.com.au/story/2077990/tailem-bend-motor-sport-plans-revealed/

Szabo JK, Vesk PA, Baxter PWJ, Possingham HP (2011) Paying the extinction debt: woodland birds in the Mount Lofty Ranges, South Australia. Emu 111: 59–70. https://doi.org/10.1071/MU09114

Tilman D, Balzer C, Hill J, Befort BL (2011) Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Science of the USA 108: 20260. https://doi.org/10.1073/pnas.1116437108

Tilman D, May RM, Lehman CL, Nowak MA (1994) Habitat destruction and the extinction debt. Nature 371: 65–66. https://doi.org/10.1038/371065a0

Traill LW, Bradshaw CJA, Brook BW (2007) Minimum viable population size: a meta-analysis of 30 years of published estimates. Biological Conservation 139: 159–166. https://doi.org/10.1016/j.biocon.2007.06.011

Traill LW, Brook BW, Frankham R, Bradshaw CJA (2010) Pragmatic population viability targets in a rapidly changing world. Biological Conservation 143: 28–34. https://doi.org/10.1016/j.biocon.2009.09.001

Tscharntke T, Klein Alexandra M, Kruess A, Steffan-Dewenter I, Thies C (2005) Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters 8: 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x

United Nations (1998) Kyoto Protocol of the United Nations Framework Convention on Climate Change. United Nations Framework Convention on Climate Change, Bonn, Germany. https://unfccc.int/kyoto_protocol/items/2830.php

United Nations (2016) The Paris Agreement. United Nations Framework Convention on Climate Change, Paris, France. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Urban MC, Tewksbury JJ, Sheldon KS (2012) On a collision course: competition and dispersal differences create no-analogue communities and cause extinctions during climate change. Proceedings of the Royal Society B 279: 2072. https://doi.org/10.1098/rspb.2011.2367

van Oosterzee P, Blignaut J, Bradshaw CJA (2012) iREDD hedges against avoided deforestation's unholy trinity of leakage, permanence and additionality. Conservation Letters 5: 266–273. https://doi.org/10.1111/j.1755-263X.2012.00237.x

Walker BH (1992) Biodiversity and ecological redundancy. Conservation Biology 6: 18–23. https://doi.org/10.1046/j.1523-1739.1992.610018.x

Walker S, Brower Ann L, Stephens RTT, Lee William G (2009) Why bartering biodiversity fails. Conservation Letters 2: 149–157. https://doi.org/10.1111/j.1755-263X.2009.00061.x

Walters CJ, Holling CS (1990) Large-scale management experiments and learning by doing. Ecology 71: 2060–2068. https://doi.org/10.2307/1938620

Waters CM, Orgill SE, Melville GJ, Toole ID, Smith WJ (2016) Management of grazing intensity in the semi-arid rangelands of southern Australia: effects on soil and biodiversity. Land Degradation and Development 28: 1363–1375. https://doi.org/10.1002/ldr.2602

Watts ME, Stewart RR, Martin TG, Klein CJ, Carwardine J, Possingham HP (2017) Systematic conservation planning with Marxan. In: Gergel S, Turner M (Eds) Learning Landscape Ecology. Springer, New York, 211–227.

Williams DR, Alvarado F, Green RE, Manica A, Phalan B, Balmford A (2017) Land-use strategies to balance livestock production, biodiversity conservation and carbon storage in Yucatán, Mexico. Global Change Biology 23: 5260–5272. https://doi.org/10.1111/gcb.13791

Wilson EO (1987) The little things that run the world (the importance and conservation of invertebrates). Conservation Biology 1: 344–346. https://doi.org/10.1111/j.1523-1739.1987.tb00055.x

Woinarski JCZ, Burbidge AA, Harrison PL (2015) Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. Proceedings of the National Academy of Science of the USA 112: 4531–4540. https://doi.org/10.1073/pnas.1417301112

Woinarski JCZ, Murphy BP, Palmer R, Legge SM, Dickman CR, Doherty TS, Edwards G, Nankivell A, Read JL, Stokeld D (2018) How many reptiles are killed by cats in Australia? European Journal of Wildlife Research 45: 247–266. https://doi.org/10.1071/WR17160

Woinarski JCZ, Woolley LA, Garnett ST, Legge SM, Murphy BP, Lawes MJ, Comer S, Dickman CR, Doherty TS, Edwards G, Nankivill A, Palmer R, Paton D (2017) Compilation and traits of Australian bird species killed by cats. Biological Conservation 216: 1–9. https://doi.org/10.1016/j.biocon.2017.09.017

World Bank (2018)World Bank Open Data. New York, USA. http://data.worldbank.org

Zhang Y, Chen HYH, Reich PB (2012) Forest productivity increases with evenness, species richness and trait variation: a global meta-analysis. Journal of Ecology 100: 742–749. https://doi.org/10.1111/j.1365-2745.2011.01944.x

Zoos South Australia (2018) Saving the yellow-footed rock wallaby. Zoos South Australia, Adelaide, South Australia. http://www.zoossa.com.au/saving-yellow-footed-rock-wallaby/

Supplementary material 1

Additional biodiversity enhancement projects in South Australia

Author: Corey J. A. Bradshaw

Data type: Literature review

Explanation note: Additional information outlining several ways the State of South Australia has been engaged in attempting to improve the prospects of its biodiversity.

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/rethinkingecology.4.32570.suppl1